Reply to the "Comment on 'Piezonuclear decay of Thorium' [Phys. Lett. A 373 (2009) 1956]" [Phys. Lett. A 373 (2009) 3795] by G. Ericsson et al.

Fabio Cardone[1], Roberto Mignani[2−4] and Andrea Petrucci[5]
[1]Istituto per lo Studio dei Materiali Nanostrutturati (ISMN – CNR)
Via dei Taurini - 00185 Roma, Italy
[2]GNFM, Istituto Nazionale di Alta Matematica "F.Severi"
Città Universitaria, P.le A.Moro 2 - 00185 Roma, Italy
[3]Dipartimento di Fisica "E.Amaldi", Università degli Studi "Roma Tre"
Via della Vasca Navale, 84 - 00146 Roma, Italy
[4]I.N.F.N. - Sezione di Roma III
[5]I.N.F.N. Laboratories - Frascati, Roma, Italy

October 13, 2009

Abstract

In a paper appearing in this issue of Phys. Lett. A, Ericsson et al. raise some critical comments on the experiment [Phys. Lett. A 373 (2009) 1956] we carried out by cavitating a solution of thorium-228, which evidenced its anomalous decay behaviour, thus confirming the results previously obtained by Urutskoev et al. by explosion of titanium foils in solutions. In this letter, we reply to these comments. In our opinion, the main shortcomings of the criticism by the Swedish authors are due to their omitting of inserting our experiment in the wider research stream of piezonuclear reactions, and to the statistical analysis they used, which does not comply with the rules generally accepted for samples with small numbers. However, apart from any possible theoretical speculation, there is the basic fact that two different experiments (ours and that by Urutskoev et al.), carried out independently and by different means, highlight an analogous anomaly in the decay of thorium subjected to pressure waves. Such a convergence of results shows that it is worth to further carry on experimental investigations, in order to get either a confirmation or a disproof of the induced-pressure anomalous behaviour of radioactive nuclides even different from thorium.

1 Introduction

In an article appearing in the present issue of *Physics Letters A*[1], G.Ericsson et al. make some comments on our paper [2], in which we report the results of an experiment investigating the possible effects of cavitation on Thorium 228. It is just the aim of this letter to reply to such comments. We are somehow grateful to the above Authors, because this gives us the occasion to clarify some points of [2] which seemingly have been misunderstood, and to deepen other ones.

In our opinion, the main shortcoming of paper [1] is the ignorance of the bibliography concerning the subject of piezonuclear reactions (refs. [4-15] of our article, we quote here again[3−15]). This prevented Ericsson et al. from putting our work [2] in this wider research stream, thus isolating it from its natural context and misinterpreting its aims and results (although we stated them in a quite clear way in the Introduction of [2]).

In short, piezonuclear reactions are nuclear reactions (of a new kind) induced in liquids by ultrasound cavitation[3−8] and in solids by mechanical pressing and consequent brittle failure[9]. Such processes give rise to transformations of elements[3−5] and to emission of neutrons[7,9,15], *without significant emission of gamma radiation.* Moreover, piezonuclear reactions are characterized by a marked threshold behaviour in the supplied energy, and occur *in stable elements.* Therefore, they do not belong to the research stream aimed at inducing *usual* nuclear reactions in unstable elements or deuterated compounds[16−19] by means of pressure waves (in particular ultrasounds and cavitation), but constitute new phenomena involving the nucleus. A possible theoretical interpretation of such new processes and of their features (in terms of a spacetime deformation) has been given in refs.[6,8].

A research stream parallel to ours is given by the experiments, carried out by Russian teams at Kurchatov Institute and at Dubna JINR, on the effects of electric explosion of titanium foils in liquids[10−13]. Analogous experiments are presently being performed at the Nantes GeM laboratory[14]. Besides observing transformation of elements (like in our experiments [3-5]), the Russian researchers ascertained a violation of the secular equilibrium of Thorium 234.

It was spontaneous for us to formulate the hypothesis that piezonuclear reactions are at the basis of Russian results, namely that the explosion of titanium foils gives rise to pressure waves in liquids able to generate effects similar to cavitation. The simplest way to verify such a hypothesis was just to carry out the experiment described in [2], i.e. to subject to cavitation not stable nuclides (as we did in our previous experiments[3−9,15]), but a radioactive one, we chose as Th^{228} in order to compare our results with the Russian ones.

This is the general context in which the experiment of paper [2] must be inserted in order to fully appreciate its results. Our claim about the piezonuclear decay of Thorium 228 is not based only on the experiment [2], but is corroborated by our previous experiments and by those of the Russian researchers. In particular, the statement in the Abstract of [1] that "..*a number of additional tests [that] should be made in order to improve the quality of the study and test the*

hypothesis of so-called piezonuclear reactions"[1] is invalidated by the results of the experiments [3-9,15], which show a quite clear evidence for reactions induced by pressure (even neglecting the Russian experiments).

Therefore, the comments by Ericsson et al. apply at most to the results of ref.[2]. Then, let us discuss in detail their main objections.

2 Reply to Comments

2.1 Placement of detectors

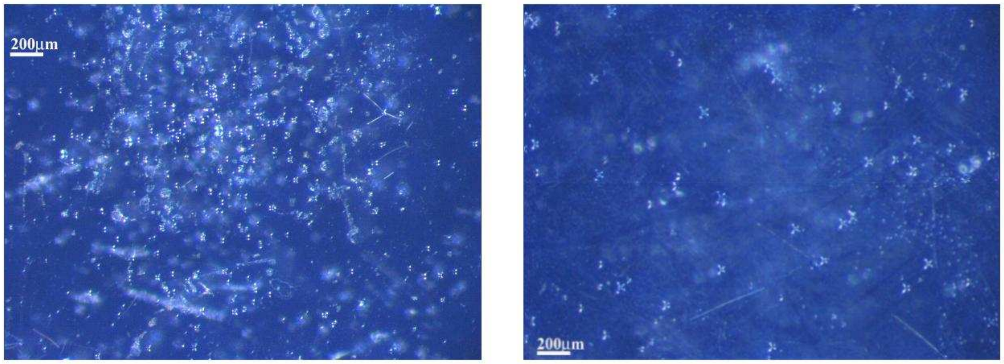
Obviously, the detectors CR39 where not placed *below* the cavitation chamber, but *inside it on the bottom*. The error was due to an improper use of the word "underneath" (which may in some case mean "inside on the bottom"). During two years of discussions of the results with our colleagues not directly involved in the experiment, it escaped our and our colleagues revision of the manuscript, just because it was obvious for us and for them that the CR39 were *inside* the vessel (by the way, their placement was taken for granted also by the referee, who made no objections on this point). Needless to say, we strongly apologize for this misprint, and are grateful to Ericsson et al. for allowing us to clarify this fundamental point.

2.2 The α- traces on CR39

With regard to the traces on the CR39 plates, we had already put in practice the suggestion of the Authors of [1], namely "*...To investigate the nature of the observed traces in the CR39 detectors, we suggest that the authors conduct further background measurements, e.g., measurements during cavitation of pure water, or with empty vessels, but in other respects identical to what is done with the thorium solutions"*[1]. In fact, in the experiments reported in refs.[6,15] we cavitated mere bidistilled deionized water, by using two CR39, one inside and the other below the cavitation chamber. We report here in Fig.1 the pictures of the CR39 plates (already published in ref.[6], p.260).

No trace on them does vaguely resembles those observed in the thorium experiment[2]. Moreover, the identification of the α-traces was independently made by dr. G. Cherubini, of the University of Roma "La Sapienza", formerly at CAMEN (Center for Military Applications of Nuclear Energy), who prides himself on decades-long experience in this field.

As to the number of detected α-traces, our estimate of the radioactivity of Thorium 228 is about one order of magnitude smaller than that evaluated by the Authors of ref.[1]. But obviously this is not the reason whereby we observed such a low number of decaying events. This is instead due to the very objection raised by Ericsson et al. (see Subsect.2.2) on the range of α-particles. Clearly, since α-particles in water have a very short range, the CR39 placed inside the vessel is able to detect the decay of a nucleus of thorium only if it is immediately near to



a b

Figure 1: Showing the magnified central parts of the CR39 immersed in water, on the bottom of the vessel (a) and of that below the vessel (b) for cavitation of pure water. See refs.(6,15).

(or even in touch with) the CR39 plate. We are amazed at the fact that the Authors of [1] did not apply their own objection, based on the range of α-particles, to understand the low number of observed traces.

2.3 Increased Thorium radioactivity and γ-emission

Another misunderstanding of Ericsson et al. is to deduce that, since there was a halving of the Thorium activity (and of the Thorium content in the solutions) due to cavitation, this would imply an increase of thorium radioactivity. Then, as a consequence, *"..the detectors monitoring the cavitated solutions should not show fewer but four orders of magnitude more events"*[1]. This interpretation is based on the assumption that thorium transformation proceeds through the usual decay channels, whereas in our interpretation — supported by our previous experiments — thorium is halved by means of piezonuclear reactions without increasing its radioactivity.

By this token, the test suggested in [1] in order to check the presumed increase of radioactivity of thorium, based on the analysis of γ radiation, is invalidated by the fact that piezonuclear reactions occur without γ emission. We fully agree with Ericsson et al. that this "*. . . would constitute a second extraordinary claim which would need separate careful study, documentation and verification."*[1]. The point is that we already verified such an "extraordinary" fact in the previous fifteen years of experiments[3–9,15] (let us also stress that such a feature, namely the absence of γ radiation is present also in the Russian experiments[12,13], and in some experiments of Low Energy Nuclear Reactions[20]).

2.4 Statistical analysis

Concerning the statistical analysis, it was not our aim to carry out a precise inferential statistical analysis in order to ascertain with a very low level of significance if the reduction of radioactivity observed in the cavitated samples were due not to chance, but to cavitation itself. Actually, as already stressed, our paper [2] must be inserted in the context of the evidences from other analogous experiments, in which cavitation was shown to induce "anomalous" nuclear effects.

However, by going into details, it is not correct from a methodological viewpoint — as instead done in [1] — to apply the test t of Student to so scarce samples (in number of 3), although it holds for low samples but anyway generally and basically not lower than 5÷7 (see [21]). Moreover, in paper [1], it is specified neither on what variable (counts or concentrations) the test was performed, nor on what numbers and on what calculation instrument it is based the value of 0.26 for p-value.

The Authors of [1] also state that the value of the p-value needed to rejecting the null hypothesis must be lower than 0.01, whereas in general it is usual to consider the value 0.05 as a limit[1]. However, even a so stringent limit does not exist in any kind of inferential analysis, and the assumed limiting values are largely conventional(22).

Therefore, we decided to carry out, in our turn, the t-test, deeming it the most suited to the present case, although in presence of few data.

We utilized the software environment R, the most used by the international scientific community for statistical computing, so anyone can easily test our results.

By using the two-tailed t-test, with null hypothesis that both the cavitated and the uncavitated sample belong to the same distribution and with alternative hypothesis that the cavitated sample has values lower than the uncavitated one, we found, by simply executing the t-test function, a p-value of 0.062 on concentrations and of 0.065 on counts.

These values are definitely lower than those reported by Ericsson et al.. We can therefore clearly state that the probability that the observed differences, by accepting the null hypothesis, are due to chance, is only 6%. Then, it is reasonable to reject the null hypothesis and to accept the alternative hypothesis with a significance level of 6%, very near to the 5% usually accepted by the scientific community.

Let us notice that for scarce samples, as in the present case, it is even more difficult, compared to bigger samples, rejecting the null hypothesis. Therefore, the statistical result we obtained from the data of our experiment has actually a great statistical meaning. This largely balances also the (not low) inhomogeneity of the initial concentrations of all used (both cavitated and reference) samples. It must be also taken into account the difficulties of getting very uniform concentrations, owing to the environmental and sanitary dangerousness of thorium.

[1] We recall that the "rule" of considering as significant p-values near to zero is erroneously justified by misinterpreting the p-value as the probability that the null hypothesis is true. For such a point and the so-called Jeffreys-Lindley paradox, see ref.[21].

Then, although all the laboratory expedients have been utilized in order to get the maximum homogeneity in the concentrations of all samples, the obtained inhomogeneity is actually an instrumental constraint inherent to the experiment itself.

In our opinion, apart from the initial inhomogeneity of the samples (controlled and optimized compatibly with the experimental and technical constraints), what does matter and was indeed observed is the halving of the thorium content in the cavitated samples with respect to the uncavitated ones, in agreement with the result obtained from the traces on the CR39 detectors.

3 Conclusions

At the light of the above reply to the comments by Ericsson et al. , we can state that our experiment [2] has hit the two main aims we proposed to ourselves, namely: 1) to verify the effect of pressure waves on thorium decay, in agreement with the findings by Urutskoev et al.; 2) to confirm the role of piezonuclear reactions in such a decay.

In our opinion, the main shortcomings of the criticism by the Swedish authors(1) are due to their omitting of inserting our experiment in the wider research stream of piezonuclear reactions, and to the statistical analysis they used, which does not comply with the rules generally accepted for samples with very small numbers. However, apart from any possible theoretical speculation, there is the basic fact that two different experiments (ours and that by Urutskoev et al.), carried out independently and by different means, highlighted an analogous anomaly in the decay of thorium subjected to pressure waves. Such a convergence of results shows that it is worth to further carry on experimental research, in order to get either a confirmation or a disproof of the anomalous behaviour of radioactive nuclides (even different from thorium) induced by pressure. On this point, we fully agree with Ericsson et al. on the fact that our results must be corroborated and confirmed by further and more refined investigations. It was just one of the scopes of our paper [2] to stimulate the scientific community in this sense, also on account of the possible technology and application spin-off of our results. And, after all, an experiment can only be really confirmed or confuted by another experiment.

Acknowledgments. We warmly thank W. Perconti, of the Data Analysis Branch ISPRA (High Insttute for Enviromental Research), for very useful discussions and enlightening comments..

References

[1] G. Ericsson, S. Pomp, H. Sjöstrand and E. Traneus: *Phys. Lett. A* (this issue).

[2] F. Cardone, R. Mignani and A. Petrucci: *Phys. Lett. A* **373**, 1956 (2009).

[3] F. Cardone and R. Mignani: in *Proc. Int. Conf. On Cosmoparticle Physics "Cosmion 2001"* (Moscow, Russia, May 2001), *Grav. and Cosmol. Suppl.* **8**, 216 (2002).

[4] F. Cardone and R. Mignani: *Int. J. Mod. Phys. B* **17**, 307 (2003).

[5] F. Cardone, R. Mignani, W. Perconti, E. Pessa and G. Spera: *Jour. Radioanalytical Nucl. Chem.* **265**, 151 (2005).

[6] F. Cardone and R. Mignani.: *Deformed Spacetime* (Springer, Heidelberg-Dordrecht, 2007).

[7] F. Cardone, G. Cherubini and A. Petrucci: *Phys. Lett. A* **373**, 862 (2009).

[8] F. Cardone and R. Mignani: *Int. Jour. Modern Phys. E* **15**, 911 (2006).

[9] A. Carpinteri, F. Cardone and G. Lacidogna: *Strain: Int. J. Exp. Mech.* **45**, 332 (2009).

[10] L.I. Urutskoev, V.I. Liksonov and V.G.Tsinoev: *Applied Physics (Russia)*, **4**, 83 (2000); *Ann. Fond. L.de Broglie* **27**, 701 (2002).

[11] V.D. Kuznetsov, G.V. Myshinskii, V.I. Zhemennik, and V.I.Arbuzov: "Test Experiments on Observation of Cold Transmutation of Elements", *Proc. 8-th Russ. Conf. on the Cold Transmutation of Nuclei of Chemical Elements* (Moscow, 2001), p.308.

[12] A.G. Volkovich, A.P. Govorun, A.A. Gulyaev, S.V..Zhukov, V.L. Kuznetsov, A.A. Rukhadze, A.V. Steblevskii and L.I.Urutskoev.: *Bull. Lebedev Physics Inst.*, 2002 (8).

[13] For a review, see L.I. Urutskoev: *Ann. Fond. L.de Broglie* **29**, 1149 (2004).

[14] D. Priem, G. Racineux, G. Lochak, C. Daviau, D. Fargue, M. Karatchentcheff and H. Lehn: *Ann. Fond. L.de Broglie* **33**, 129 (2008).

[15] F.Cardone, G. Cherubini, R. Mignani, W. Perconti, A. Petrucci, F. Rosetto and G. Spera: www.arxiv.org/abs/0710.5115.

[16] K. Diebner: *Kerntechnik* n.3, 89 (1962); S. Kaliski: *Nature* **269**, 370 (1977); A.S. Kozirev, V.A. Aleksandrov, N.A. Popov: *Nature* **275**, 476 (1978); F. Winterberg: *Atomenergie-Kerntechnik* **44**, 146 (1984).

[17] R.P. Taleyarkhan *et al.*: *Science* **295**, 1868 (2002); *Phys. Rev. E* **69**, 036109 (2004); *Phys. Rev. Lett.* **96**, 034301 (2006).

[18] Y. Xua and A. Butt: *Nuclear Engineering and Design* **235**, 1317 (2005); Nigmatulin et al.: *J. Power and Energy* **218** Part A (2004); *Physics of Fluids* **17**, 107106 (2005); E. Forringer et al.: *Archives of American Nuclear Society*, Albuquerque, NM, pg.736-737, Nov.2006; also, *Proc. Int. Conf. Nuclear Fusion Energy*, Albuquerque, NM, Nov. 2006.

[19] R.P. Taleyarkhan *et al.*: *Nuclear Engineering and Design* **238**, 2779 (2008).

[20] See e.g. E. Storms: *The Science of Low Energy Nuclear Reaction* (World Scientific, Singapore, 2007).

[21] T. Sellke, M.J. Bayarri and J. Berger: *The American Statistician* **55**, 62 (2001).

[22] J. A. Rice: *Mathematical Statistics and Data Analysis* (Duxbury Resource Center, 2006).